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D. D. Huff
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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1504

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## ABSTRACT


STUEBER, A. M., D. D. HUFF, N. D. FARROW, J. R. JONES, and I. L. MUNRO. 1981. An evaluation of some $^{90}Sr$ sources in the White Oak Creek drainage basin. ORNL/TM-7290. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 48 pp.

The drainage basin was monitored to evaluate the relative importance of each source as a contributor to $^{90}Sr$ in White Oak Creek. The various sources fall into two general categories, those whose $^{90}Sr$ discharge is dependent upon rainfall and those relatively unaffected by the level of precipitation. Solid waste disposal area (SWDA) 4 is definitely the most important $^{90}Sr$ source in the drainage basin, but during extended periods of low rainfall its discharge is exceeded by that from SWDA 5 and by plant discharges, both of which are relatively constant in magnitude. The method of determining the $^{90}Sr$ discharge from SWDA 4 used in the past led to overestimates because other sources in the area were included in the difference between upstream and downstream monitoring stations, and thus attributed to SWDA 4. Monitoring station 2A, recently installed on White Oak Creek between SWDA 4 and these sources, will permit more reliable estimates of the $^{90}Sr$ discharge from SWDA 4 to be made on a regular monthly basis by the difference method.

Indirect determinations of the apparent $^{90}Sr$ discharge from contaminated floodplain no. 1, located on the east side of White Oak Creek between the ORNL plant area and Haw Ridge and adjacent to SWDA 4, indicate that this floodplain represents a significant $^{90}Sr$ source during periods of relatively high precipitation. The $^{90}Sr$ discharged

by the Northwest tributary to White Oak Creek seems to be relatively constant except during extended dry periods when it decreases, apparently due to the hydrologic conditions that prevail in and around SWDA 3.

The identification and ranking of existing non-point sources of $^{90}Sr$ in the White Oak Creek basin represents an important step in the ongoing comprehensive program at ORNL to provide a scientific basis for improved control measures and future disposal practices in solid waste disposal areas.

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# INTRODUCTION

Since the mid-1940s, considerable amounts of wastes contaminated by radionuclides have been accumulated by Oak Ridge National Laboratory for disposal. The low-level wastes were (and continue to be) buried in solid waste disposal areas (SWDAs), while other methods were used to deal with intermediate-level radioactive wastes. Studies showed that some of the radionuclides that were buried as low-level waste migrated to surface waters draining from the White Oak Creek basin (e.g., Duguid 1975, Lomenick et al. 1963) and contributed a portion of the total discharge of radionuclides from ORNL to the Clinch River.

Based on $^{90}Sr$ discharge data gathered during routine environmental surveillance sampling (Oakes and Shank, 1979) and observed flows at White Oak dam, the mean annual $^{90}Sr$ concentration of water discharged at White Oak dam for the period 1973-1976 was calculated as 134 ± 26% of the maximum permissible concentration for drinking water ($MPC_w$). However, for 1977 and 1978, similar calculations show that the annual average $^{90}Sr$ concentration in water at White Oak dam was 70 ± 7% of $MPC_w$, even though precipitation and runoff totals were quite similar to those for previous years. These recent declines indicate the value of an active program designed to identify and reduce or eliminate radionuclide discharges to White Oak Creek.

As part of an ongoing program to significantly reduce the $^{90}Sr$ discharge from the White Oak drainage, studies were conducted to identify and rank present sources as the basis for devising effective control measures. Evaluation of stream-monitoring data collected at five stations within the White Oak Creek drainage basin (Fig. 1) shows the relative importance of sources between monitoring stations 2 and 3 (MS2 and MS3) compared to measured discharge at White Oak dam (Table 1, column 7). In 1976 and 1977, the sources between MS2 and MS3 were equivalent to over 90% of the total $^{90}Sr$ discharge at MS5. It should be noted, however, that the combined inflow of $^{90}Sr$ to White Oak Lake (MS3 + MS4) exceeds the outflow measured at MS5. This probably indicates leakage at the dam, but could represent net accumulation of $^{90}Sr$ in White Oak Lake sediments or a combination of measuring uncertainties at all three locations. When compared with $^{90}Sr$ inflow to White Oak Lake, the incremental difference between MS2 and MS3 was about 70% of the total for 1976 and 1977. Although this increment of $^{90}Sr$ has commonly been attributed to discharge from SWDA 4 (Fig. 1), a comprehensive study carried out in December 1977 revealed that two other sources, Waste Ponds 3539 and 3540 and the sewage treatment plant, were of comparable importance at that time (Stueber et al. 1978). Since then, the Operations Division has reduced the $^{90}Sr$ discharge from the waste ponds to about 1% of the contribution between MS2 and MS3. There has been a corresponding marked reduction in the $^{90}Sr$ discharge recorded at monitoring stations 3 and 5 in 1978 compared with previous years (Table 1), although it is not certain that these improvements are solely a result of this single corrective measure. Nevertheless, the $^{90}Sr$ discharges for 1978 at these two monitoring stations represent the lowest values on record since disposal began, even though simultaneous $^{90}Sr$ discharges recorded

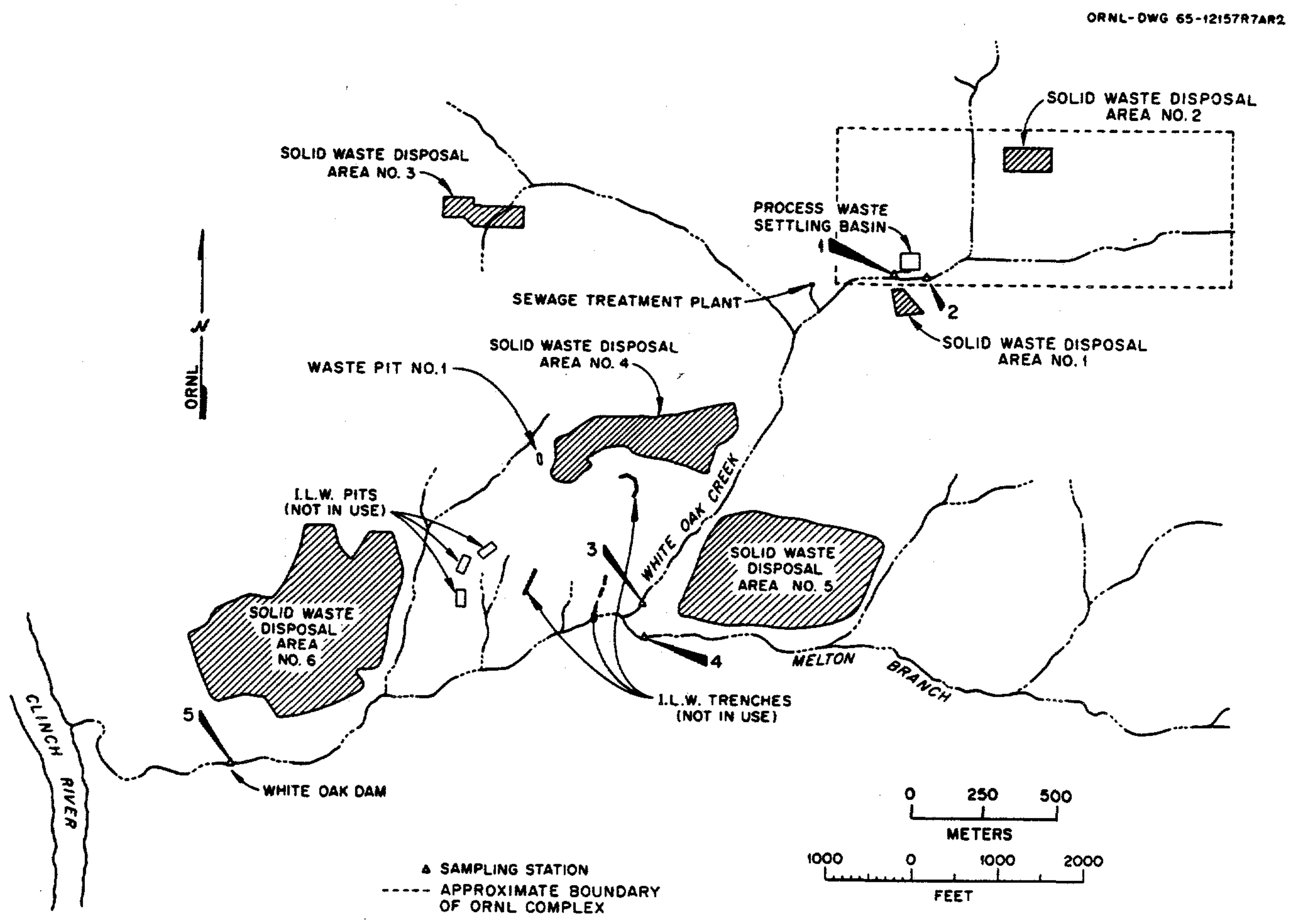


Fig. 1. Approximate locations of waste disposal areas and sampling stations at ORNL.

Table 1. Total Sr (Ci) discharged at ORNL monitoring stations (see Fig. 1 for locations). Data collected from monthly reports of radioactive waste disposal operations and effluent monitoring.

| Calendar year | Monitoring Stations | | | | | 3-(1+2) | $\frac{3-(1+2)}{5} \times 100$ | Precipitation (cm) | 3-(1+2)/precip. (mCi/cm) |
|---|---|---|---|---|---|---|---|---|---|
| | 5 | 4 | 3 | 2 | 1 | | | | |
| 1964 | 7.28 | 0.69 | 6.47 | 0.19 | 2.99 | 3.29 | 45.2 | 115 | 28.6 |
| 1965 | 4.17 | 0.31 | 5.13 | 0.25 | 1.48 | 3.40 | 81.5 | 122 | 27.9 |
| 1966 | 3.86 | 0.47 | 5.45 | 0.14 | 3.31 | 2.00 | 51.8 | 127 | 15.7 |
| 1967 | 5.82 | 0.95 | 6.87 | 0.13 | 4.06 | 2.68 | 46.1 | 161 | 16.6 |
| 1968 | 3.29 | 2.80 | 4.05 | 0.13 | 2.19 | 1.73 | 52.6 | 93 | 18.6 |
| 1969 | 3.33 | 0.92 | 3.37 | 0.39 | 1.69 | 1.29 | 38.7 | 114 | 11.3 |
| 1970 | 4.17 | 0.74 | 3.68 | 0.38 | 1.95 | 1.35 | 32.4 | 114 | 11.8 |
| 1971 | 3.40 | 0.61 | 3.45 | 0.19 | 1.54 | 1.73 | 50.9 | 123 | 14.1 |
| 1972 | 6.00 | 0.91 | 6.18 | 0.29 | 3.71 | 2.18 | 36.3 | 146 | 14.9 |
| 1973 | 6.33 | 1.30 | 5.27 | 0.70 | 2.58 | 1.99 | 31.4 | 195 | 10.2 |
| 1974 | 6.08 | 1.30 | 8.93 | 0.78 | 2.80 | 5.35 | 88.0 | 146 | 36.6 |
| 1975 | 7.15 | 2.14 | 7.13 | 0.24 | 3.29 | 3.60 | 50.4 | 154 | 23.4 |
| 1976 | 4.51 | 0.67 | 6.08 | 0.43 | 1.38 | 4.27 | 94.7 | 133 | 32.1 |
| 1977 | 2.71 | 0.49 | 2.87 | 0.22 | 0.09 | 2.56 | 94.5 | 159 | 16.1 |
| 1978 | 2.00 | 0.54 | 1.56 | 0.21 | 0.11 | 1.23 | 51.5 | 134 | 9.2 |

upstream at monitoring stations 1 and 2, and on Melton Branch at station 4, show no significant changes over the preceding year. In other words, the relative importance of non-point sources has increased as the total $^{90}Sr$ discharged through White Oak Creek has been reduced.

The purpose of this report is to present a re-evaluation of the remaining $^{90}Sr$ sources in the White Oak Creek basin in an attempt to rank their relative importance. This ranking should serve as a guide to the implementation of future corrective measures and contribute to the evaluation of their effectiveness. It should also be useful in the development of future disposal practices, through the identification of existing problem areas. The work reported here concentrates on sources between monitoring stations 2 and 3, but also considers the SWDA 5 area (above monitoring station 4) for the sake of completeness. The approach used in the study was to select specific sites and sample streamflow rate and $^{90}Sr$ concentration at daily intervals. These data form the basis for estimating monthly total $^{90}Sr$ discharge at each site. By examining differences between sites, it was possible to locate the major sources and rank their importance.

## STREAM SAMPLING AND FLOW MEASUREMENTS

### Discharge Measurements

Water samples and streamflow measurements were obtained during the period September 1978 through January 1979 at the temporary monitoring stations shown in Fig. 2. Initially, data were collected at only a few sites, and the sampling program expanded in scope during the five-month

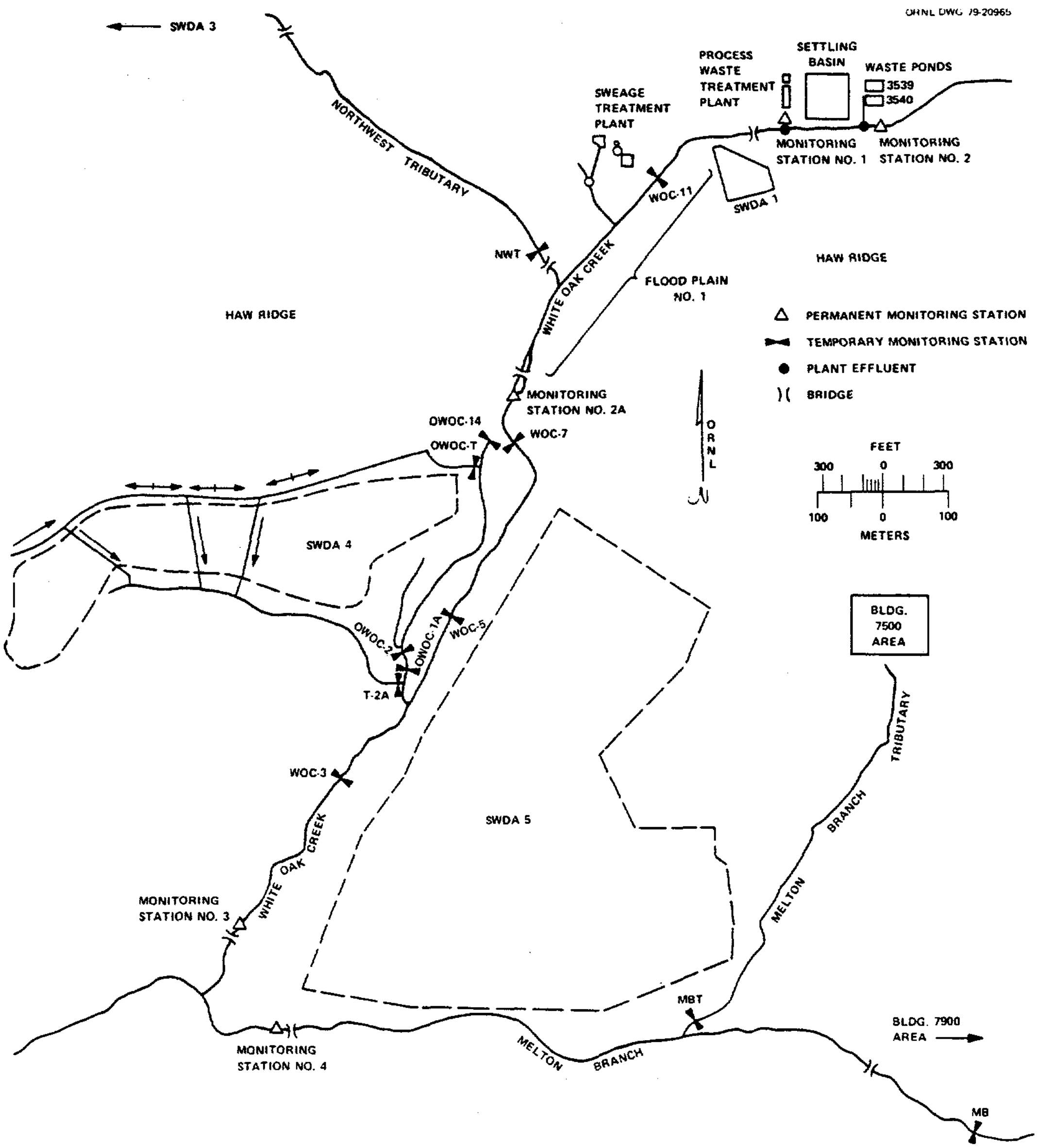


Fig. 2 Locations of $^{90}Sr$ sources and monitoring sites considered in this investigation.

period as dictated by early results. In general, we relied heavily on data reported monthly by the Operations Division to supplement our limited results.

Streamflow measurements were made in several ways. Staff gauge readings were taken on a daily basis at each of the following locations shown in Fig. 2: the Northwest Tributary (NWT), Melton Branch (MB), and Melton Branch Tributary (MBT). Streamflow values were obtained from stage-discharge rating curves that had been established previously (Laib and Huff 1978). A portable Parshall flume was installed in the stream that flows south of SWDA 4 (Fig. 2, T-2A), where daily readings were taken and converted to streamflow values.

The flow at various locations in the old channel of White Oak Creek (OWOC) was measured each day through the use of a stopwatch and either a 9.7- or 21-liter collection vessel. Collection was facilitated at two locations (Fig. 2, OWOC-2 and OWOC-T) through the construction of earthen dams. At OWOC-14, surface runoff from Haw Ridge flows through a culvert and falls into the creek channel, permitting direct collection. The site identified as OWOC-1A represents a seep flowing from the bank of the creek channel; a small metal trough was installed to allow collection of the effluent.

Streamflow measurements were made in White Oak Creek at four locations between monitoring stations 2 and 3: WOC-3, WOC-5, WOC-7, and WOC-11 (Fig. 2). During November 1978 between 12 and 16 flow determinations were taken at each location with a vertical-axis current meter, using the midsection method of measurement (Buchanan and Somers 1969). The measurements were made to determine the ratio between the streamflow at each of these sites and that at monitoring station 3, which is recorded continuously. The flow volume at a particular site for a specific interval of time can then be determined from the ratio at that site and the flow volume recorded at station 3. Therefore, each measured flow value was divided by the flow at station 3, taking into account the estimated travel time between the upstream site and the monitoring station.

The mean flow ratios for each site are presented in Table 2, along with the flow range over which the readings were taken. At stations WOC-3 and WOC-5 the flow ratio was essentially unity under all flow conditions, in agreement with the results of measurements taken in a previous study (Stueber et al. 1978). The flow ratios at sites WOC-7 and WOC-11 were found to change with the flow conditions due to variable contributions from tributary streams.

Examination of flow records at White Oak dam show that the total volume discharged during the study period was within 5% of the comparable mean for 1967-1979. Similarly, precipitation was within 2% of the normal value for the period. However, the flow volume for September 1978 was approximately double the mean value, and that for November was about half the mean. Volumes during other months were within one standard deviation of the respective means. The range of flow values observed during the study period (.3 - 2.2 x $10^6$ $m^3$) compares favorably to the full range observed for all months between 1967 and 1979 (.3 - 2.5 x $10^6$ $m_3$).

Table 2. Streamflow ratios at four sites in White Oak Creek relative to the flow at monitoring station 3

| Site | Flow ratio | n | Flow range ($m^3/sc$) |
|---|---|---|---|
| WOC-3 | 1.004 ± 0.05 | (7) | 0.131 - 0.606 |
| WOC-5 | 1.022 ± 0.05 | (12) | 0.119 - 0.606 |
| WOC-7 | 1.033 ± 0.05 | (8) | 0.119 - 0.178 |
| | 0.910 ± 0.03 | (3) | 0.300 - 0.612 |
| WOC-11 | 0.744 ± 0.02 | (6) | 0.125 - 0.185 |
| | 0.62 ± 0.02 | (4) | 0.277 - 0.915 |

## Water Sample Collection and Analysis

One-liter water samples were obtained on a daily basis at each location when flow measurements were being made during the study. Each sample was filtered through Whatman filter paper No. 42 and acidified with $HNO_3$ to pH 1-2. Composite water samples were prepared for each location, covering four or five time intervals within the month. The time intervals were established by examination of the streamflow hydrograph and selection of periods with approximately uniform conditions during both high and low flows.

The composite water samples were analyzed for $^{90}Sr$ by the Analytical Chemistry Division. For each location studied during a particular month, the $^{90}Sr$ activity in each composite water sample was combined with the integrated streamflow for that time interval to yield the $^{90}Sr$ discharge increment. These data are tabulated in Appendix A. The monthly $^{90}Sr$ discharge at each site during the period of this investigation is given in Table 3 with data for locations in the study area which are monitored by the Operations Division.

The method of measuring $^{90}Sr$ discharge employed in this study is limited by the fact that both stream water and stream flow were sampled just once each day rather than on a continuous basis as is done at permanent monitoring stations. The uncertainty introduced is probably not important when conditions are steady or are changing gradually because interpolations are valid, but it is probably significant during storm events.

Table 3. Monthly $^{90}Sr$ discharge (mCi) at each location monitored during this investigation, and data from locations in the study area which are monitored by the Operations Division

| Site | 9-78 | 10-78 | 11-78 | 12-78 | 1-79 |
|---|---|---|---|---|---|
| Monitoring station No. 2 | 11.0 | 28.2 | 9.7 | 14.2 | 24.2 |
| Waste ponds 3539 and 3540 | 0.6 | 1.0 | 2.3 | 1.2 | 0.6 |
| Process waste treatment plant | 2.0 | 1.5 | 0.3 | 9.1 | 2.4 |
| Sewage treatment plant | 8.0 | 5.0 | 5.5 | 13.2 | 13.8 |
| Monitoring station No. 3 | 28.0 | 37.0 | 84.5 | 174.1 | 362.7 |
| Monitoring station No. 4 | 38.0 | 21.0 | 38.0 | 46.0 | 42.1 |
| Northwest Tributary | 3.2 | 2.1 | 4.0 | 10.5 | 11.1 |
| Floodplain No. 1 (apparent) | - | - | 13.8 | 22.9 | 33.4 |
| WOC-3 | - | - | 91.1 | 170.3 | - |
| WOC-5 | - | - | 45.1 | 67.4 | - |
| WOC-7 | - | - | 39.3 | 71.1 | - |
| WOC-11 | - | - | 16.0 | - | - |
| T-2A | 7.5 | 0.8 | 13.6 | 99.8 | - |
| OWOC-2 | - | - | - | 10.4 | - |
| OWOC-1A | - | - | - | 0.7 | - |
| OWOC-14 | - | - | - | 0.0 | - |
| OWOC-T | - | - | - | 0.2 | - |
| Melton Branch | 0.9 | - | - | - | - |
| Melton Branch tributary | 5.2 | - | - | - | - |

# RESULTS

## Evaluation of $^{90}Sr$ Sources

As noted earlier, the section of White Oak Creek between monitoring stations 2 and 3 (Fig. 1) contains the major non-point sources of $^{90}Sr$ that are discharged at White Oak dam. Thus, the initial basis for identifying and ranking these sources was an examination of the data previously given in Table 3. The incremental monthly discharge associated with various sections of White Oak Creek was calculated, grouped into categories, and given as relative contribution to the reach between monitoring stations 2 and 3 (in percent) in Table 4. It is important to note that there is a marked change in weather, associated with the transition from a dry fall period to a wet winter season. In general, the relative importance of each source varied with season during the study. For our purposes, we rank the sources indicated in Table 4 based on their relative contribution to their combined total discharge observed during the full study period. Using this ranking, the important sources during the study were SWDA 4 (71.9%), floodplain No. 1 (11.7%), the sewage treatment plant (7.6%), the Northwest Tributary (5.2%), the process waste treatment plant (2.6%), and the Waste Ponds 3539 and 3540 (1%). More detailed discussion of each of these sources is presented below, in descending order of importance.

Table 4. The relative importance of some $^{90}Sr$ sources, expressed as the percent contribution to the net $^{90}Sr$ discharge between monitoring stations 2 and 3 for each month during the period of this investigation

| Source | 9-78 | 10-78 | 11-78 | 12-78 | 1-79 | Total period |
|---|---|---|---|---|---|---|
| Waste ponds 3539 and 3540 | 3.5 | 10.4 | 3.1 | 0.7 | 0.2 | 1.0 |
| Process waste treatment plant | 11.8 | 15.6 | 0.4 | 5.7 | 0.7 | 2.6 |
| Sewage treatment plant | 47.1 | 52.1 | 7.4 | 8.3 | 4.1 | 7.6 |
| Northwest Tributary | 18.8 | 21.9 | 5.3 | 6.6 | 3.3 | 5.2 |
| Floodplain No. 1 | - | - | 18.4 | 14.3 | 9.9 | 11.7 |
| SWDA 4[a] | 18.8 | 0.0 | 65.4 | 64.4 | 81.9 | 71.9 |
| Precipitation (cm) | 3.5 | 2.9 | 13.3 | 17.6 | 17.9 | 55.2 |

[a]Contribution determined by the indirect method.

SWDA 4

Strontium-90 from SWDA 4 comes from two sources. Part is discharged at monitoring site T-2A (Table 3) via the stream that lies to the south of this disposal area (Fig. 2). A smaller part is discharged by ground-water movement from the eastern portion of SWDA 4, or from the adjacent contaminated floodplain area where it enters the former channel of White Oak Creek. This contribution was monitored at site OWOC-2. A seep which discharges into the former channel at OWOC-1A was also monitored. The sum of the $^{90}Sr$ discharges at these three locations can be considered as a direct measure of the total $^{90}Sr$ contribution from SWDA 4 (Table 5).

Two indirect measures are also possible. The $^{90}Sr$ discharge from SWDA 4 can be estimated as the difference between sites WOC-5 and WOC-3 (Fig. 2), which are located just above and below the confluence of the former and present channels of White Oak Creek. Another indirect measure is the difference between the sum of $^{90}Sr$ discharge from all monitored sources and that observed at the permanent monitoring station 3. Comparisons between these methods are shown in Table 5. The agreement between indirect methods would not have been achieved without the inclusion of contributions from the Northwest Tributary and from floodplain No. 1, two sources which were not considered in the past when the indirect method was applied.

The bulk of the stream flow in the former channel of White Oak Creek is generated by surface runoff from Haw Ridge, which passes through culverts under the road north of SWDA 4 and enters the channel at locations OWOC-14 and OWOC-T (Fig. 2). Although this runoff is

Table 5. The discharge of $^{90}Sr$ (mCi) from SWDA 4 determined by various methods

| Method | 9-78 | 10-78 | 11-78 | 12-78 | 1-79 |
|---|---|---|---|---|---|
| Indirect | 3.2 | 0.0 | 48.9 | 103.0 | 277.2 |
| (WOC-3) - (WOC-5) | - | - | 46.0 | 102.9 | - |
| (T-2A + OWOC-2 + OWOC-1A) | - | - | - | 110.9 | - |

presumably devoid of $^{90}Sr$, the discharge at each of these sites was monitored during December 1978 (Table 3). The negligible quantities recorded prove that the total $^{90}Sr$ monitored at OWOC-2 for the month can be attributed to SWDA 4 and the adjacent contaminated floodplain. Approximately 10% of the total $^{90}Sr$ from SWDA 4 was discharged through the former creek channel, whereas about 90% was transmitted via the stream south of the disposal area (Table 3).

During periods of relatively high precipitation, SWDA 4 accounted for at least 65% of the $^{90}Sr$ discharged to White Oak Creek between monitoring stations 2 and 3 (Table 4). Data collected in October during an extended period of low rainfall suggest that $^{90}Sr$ discharge is markedly lower during late summer and fall, when plant effluents assume a much greater relative importance because of reduced natural flows. On an annual basis, assuming 65% of the $^{90}Sr$ increment between stations 2 and 3 comes from SWDA 4, a total of 0.88 Ci was discharged from this area in 1978.

Floodplain No. 1

Floodplain No. 1 is one of four contaminated low-lying areas adjacent to White Oak Creek in the reach between monitoring stations 2 and 3 (Stueber et al. 1978). It is located on the east side of White Oak Creek between the ORNL plant area and the bridge that crosses the creek at Haw Ridge (Fig. 2). Because the $^{90}Sr$ discharge from the floodplain to White Oak Creek cannot be measured directly, the contribution must be evaluated by indirect means.

Discharge of $^{90}Sr$ from floodplain No. 1 to the creek should be reflected in the incremental change between monitoring sites WOC-11 and WOC-7, after correction for the contributions from the sewage treatment plant and the Northwest Tributary. Such a calculation for November 1978 yields an apparent $^{90}Sr$ discharge of 13.8 mCi from this floodplain (Table 3). Although the WOC-11 site was not monitored during December 1978, an apparent floodplain contribution can be obtained from the discharge recorded at WOC-7 by subtracting the sum of the contributions from all monitored upstream sources. A similar calculation can be made for January 1979, when data were reported at monitoring station 2A (Fig. 2) by the Operations Division.

The magnitude of the apparent $^{90}Sr$ discharge from floodplain No. 1 is significant when compared with the discharges recorded at monitoring sites for November through December 1979 (Table 3). The apparent relative importance of this source (Table 4) is comparable to that of the plant effluents taken as a group, and is exceeded only by SWDA 4. We cannot be certain that these $^{90}Sr$ increments are due to discharge from the floodplain, but it is clear that there is a significant non-point source (or sources) that contributes $^{90}Sr$ to this reach of White Oak Creek.

## Sewage Treatment Plant

The sewage treatment plant is the most important source among the plant effluents, and can account for about one-half the $^{90}Sr$ input to the study reach of White Oak Creek under low-flow conditions.

Northwest Tributary

The source of most $^{90}Sr$ in the Northwest Tributary is SWDA 3, located near the stream's headwaters (Fig. 1). The $^{90}Sr$ discharge of the stream was monitored during the entire period of this investigation at a location just above the confluence with White Oak Creek (Fig. 2). During the first two months when precipitation and streamflow were low, the $^{90}Sr$ discharge amounted to only a few millicuries (Table 3). Nevertheless, the Northwest Tributary was an easily identified $^{90}Sr$ contributor to the study reach of White Oak Creek, exceeded only by SWDA 4, floodplain No. 1 and the sewage treatment plant (Table 4).

While the magnitude of the $^{90}Sr$ discharge in the Northwest Tributary increased during the latter three months of the study when precipitation was high, the $^{90}Sr$ contribution from SWDA 4 rose to a much greater extent which reduced the relative importance of the Northwest Tributary as a source (Table 4). Preliminary results of an investigation of radionuclide discharge from SWDA 3 indicate that $^{90}Sr$ migrates from this disposal area through ground-water flow over a distance of about 360 m and enters the Northwest Tributary at a point approximately 810 m upstream from the confluence with White Oak Creek. During extended periods of low precipitation the stream is not flowing at or above this location, reflecting reduced groundwater discharge and thereby explaining the low $^{90}Sr$ discharges recorded under such conditions at our monitoring site. When precipitation is higher there is continuous flow in the stream at the location of the $^{90}Sr$ ground-water source and the activity is transmitted directly downstream. However, the $^{90}Sr$ ground-water source is probably relatively steady and the $^{90}Sr$ discharge from it is not much affected by further increases in precipitation. Thus the relative importance of the Northwest Tributary as a $^{90}Sr$ source probably decreases steadily with increasing rainfall.

## Process Waste Treatment

The $^{90}Sr$ contributions from the process waste treatment plant, while of low absolute magnitude, can assume significant relative importance to the total burden in White Oak Creek during periods of low stream discharge. For example, during September and October 1978, the process waste treatment plant contributed nearly 14% of the net total discharge between monitoring stations 2 and 3. During higher flows, the relative importance decreases.

## Waste Ponds

A corrective measure implemented by the Operations Division in April 1978 reduced the $^{90}Sr$ discharge from Waste Ponds 3539 and 3540 (Fig. 2) to 1 or 2 mCi/month (Table 3). Thus, this source has been reduced to minor relative importance (Table 4) except under unusually dry weather conditions, as during October 1978 when a total of only 10.4 mCi $^{90}Sr$ was discharged to White Oak Creek from all sources between monitoring stations 2 and 3.

## Other Non-point $^{90}Sr$ Sources (SWDA 5)

Although the major portion of $^{90}Sr$ discharged from White Oak Creek appears to originate between monitoring stations 2 and 3, an evaluation of non-point sources would not be complete without consideration of other possible sources. Toward that objective, the $^{90}Sr$ contributions from SWDA 5 have also been examined.

Monitoring station 4 provides data on $^{90}Sr$ discharges to Melton Branch upstream from its confluence with White Oak Creek (Fig. 2). According to Duguid (1976), approximately 90% of the radioactivity measured at this station is attributed to SWDA 5 and the remaining 10% is from other sources in the drainage area. Both the surface and ground water flowing from SWDA 5 discharge primarily into Melton Branch.

During September 1978 we monitored the $^{90}Sr$ discharge at sites MB and MBT (Fig. 2) to determine the $^{90}Sr$ input from SWDA 5 to Melton Branch. The data (Table 3) show that 31.9 mCi $^{90}Sr$ were discharged from SWDA 5, while 0.9 mCi apparently originated in the 7900 area and 5.2 mCi were transported from the 7500 area via Melton Branch Tributary. Thus approximately 84% of the $^{90}Sr$ recorded for the month at monitoring station 4 can be attributed to SWDA 5.

The $^{90}Sr$ discharge from SWDA 5 for each month during the period of this investigation can be estimated by applying this percentage to the monthly data from monitoring station 4 (Table 3). The results (Table 6) indicate that SWDA 5 is a relatively constant source of $^{90}Sr$, independent of precipitation. In contrast, SWDA 4 represents a source whose discharge is closely related to the level of precipitation. The annual discharge of $^{90}Sr$ from SWDA 5 for 1978 can also be estimated using the assumption that 84% of the total observed at monitoring station 4 originates in SWDA 5. With this assumption, an apparent discharge of 0.45 curies can be attributed to SWDA 5 for the year.

Table 6. The discharge of $^{90}Sr$ from SWDAs 4 and 5, in millicuries and in millicuries per centimeter of precipitation

| | 9-78 | 10-78 | 11-78 | 12-78 | 1-79 |
|---|---|---|---|---|---|
| | | | $^{90}Sr$ (mCi) | | |
| SWDA 4 | 3.2 | 0.0 | 48.9 | 103.0 | 277.2 |
| SWDA 5 | 31.9 | 17.6 | 31.9 | 38.6 | 35.4 |
| Precipitation (cm) | 3.5 | 2.9 | 13.3 | 17.6 | 17.9 |
| | | | $^{90}Sr$ (mCi/cm) | | |
| SWDA 4 | 0.9 | 0.0 | 3.7 | 5.9 | 15.5 |
| SWDA 5 | 9.1 | 6.1 | 2.4 | 2.2 | 2.0 |

## DISCUSSION

As a result of the data collected during this investigation we have been able to make a reliable, direct determination of the $^{90}Sr$ discharge from SWDA 4 for monthly periods. Our measurements indicate that the indirect method used in the past to estimate this discharge is valid only if the contributions from the Northwest Tributary and from floodplain No. 1 are taken into consideration. These sources are not distinguished from SWDA 4 during routine monitoring, and it is clear from our data that they are significant. However, the recent installation of monitoring station 2A on White Oak Creek (Fig. 2) at a point downstream from these sources will make reliable estimates of the $^{90}Sr$ discharge from SWDA 4 possible on a regular monthly basis by the indirect method. Clearly the $^{90}Sr$ contributions to White Oak Creek from SWDA 4 have been overestimated in the past.

The discharge of $^{90}Sr$ from SWDA 4 is strongly dependent upon precipitation, although the dependence seems to be more a cumulative effect than a direct one. Table 6 illustrates this by contrasting the discharges from SWDA 4 and SWDA 5 in terms of discharge per unit of precipitation. During the first two months of our study when precipitation was low, the $^{90}Sr$ discharge from SWDA 4 decreased. As rainfall increased during November and December 1978, the $^{90}Sr$ discharge and the discharge per centimeter of precipitation also increased. This trend continued in January 1979 (Table 6) when the precipitation was approximately the same as during the preceding month. Thus, the discharge per centimeter of precipitation increased by a factor of about 2.6.

This behavior may be explained by the proximity of the water table to land surface in SWDA 4, and the fact that a considerable volume of runoff from Haw Ridge north of SWDA 4 passes across the area in surface diversion ditches and is discharged at the edge of SWDA 4 where it may pick up $^{90}Sr$. Measurements of water levels in wells indicate that much of the buried waste is bathed in water for at least a part of each year (Webster 1976). During prolonged dry periods, the water table is gradually lowered; the situation affects less waste in each trench and increasingly fewer trenches because of topographic variations within the disposal area. When rainfall increases, the process is reversed and the $^{90}Sr$ discharge per centimeter of precipitation rises over an extended period of time. Furthermore, during late winter, the volume of runoff that passes from the area north of Lagoon Road across SWDA 4 to White Oak Creek via the SWDA 4 tributary is greatly increased over summertime conditions. This water may be contaminated before it reaches White Oak Creek, thus resulting in increased winter discharge of $^{90}Sr$ from the SWDA 4 site.

Data from monitoring station 4 (Table 1) indicate that the yearly $^{90}Sr$ discharge from SWDA 5 has been relatively constant (neglecting 1968 when an accidental release occurred) and independent of rainfall, consistent with the observations made in this study. However, significant improvement is noted since 1975, when corrective actions were implemented in a small portion of the disposal area (Duguid 1976). At present, many of the 13 seeps located along the southern perimeter of SWDA 5 by Duguid (1976) are still active, and may represent the major source of $^{90}Sr$ discharged. However, the relatively constant rate of $^{90}Sr$ discharge also suggests that ground-water transport through the area south of SWDA 5 cannot be ruled out at this time.

The apparent discharge of $^{90}Sr$ from floodplain No. 1 increased steadily from November 1978 through January 1979 (Table 3), presumably as a result of the cumulative effects of precipitation. The soil and vegetation in this area were contaminated by flooding during storm events in the past, when the culverts which carried White Oak Creek discharge under the bridge at Haw Ridge were inadequate to accommodate the flow. The creek water contained $^{90}Sr$ from plant effluents, primarily from the former process waste treatment plant. This contamination now acts as a $^{90}Sr$ source for ground water, and for surface-runoff water from Haw Ridge. As the water table rises during extended periods of relatively high precipitation, the contaminated material in this low-lying area becomes immersed, and in some places surface ponds develop. Strontium-90 is discharged to White Oak Creek through ground-water flow and surface runoff.

The $^{90}Sr$ in buried waste within SWDA 3 is probably mobilized through surface infiltration of precipitation and movement through the trenches to the deeper water table. An effective surface seal would probably reduce $^{90}Sr$ discharge considerably. The preliminary results of our investigation of radionuclide discharge from SWDA 3 suggest that $^{90}Sr$ enters the Northwest Tributary at a considerable distance from the disposal area. Although the $^{90}Sr$ discharged by the Northwest Tributary to White Oak Creek did increase with increasing precipitation during the period of this investigation, this behavior is probably more a function of flow conditions in the stream near the point of ground-water discharge of $^{90}Sr$ rather than the effect of precipitation on the source in SWDA 3. Therefore the discharge from this stream is probably relatively constant except during extended dry periods, a conclusion which is substantiated by monitoring data for January 1979 (Table 3).

## SUMMARY AND CONCLUSIONS

Based on the data collected in the period September 1978 through January 1979, it is clear that there are at least two distinct seasonal patterns that determine relative importance of non-point sources. During the study period, SWDA 4 was identified as the most significant non-point $^{90}Sr$ source. This is most evident in winter and early spring when runoff and water-table elevations are highest. However, results also show that in the summer and fall seasons when discharge from the tributary south of SWDA 4 is negligible, all other sources gain in relative importance. In particular, annual estimates of $^{90}Sr$ discharge from SWDA 4 and SWDA 5 suggest that SWDA 5 releases about one-half as much $^{90}Sr$ as SWDA 4, and thus is one of the more significant non-point sources during summer low-flow periods. Data for September and October 1978 support this hypothesis. For the two-month period, SWDA 5 discharged 49.5 mCi (Table 6), while the incremental discharge between monitoring stations 2 and 3 was only 22.8 mCi.

Taken as a group, the plant effluents must still be regarded as an important source of the $^{90}Sr$ which is discharged to White Oak Creek between monitoring stations 2 and 3. When precipitation is low, plant effluents are the major source; during September and October they accounted for 62 and 73% of the $^{90}Sr$ input to this reach of the creek (Table 4). During periods of high rainfall (November and December 1978), they still account for between 5 and 15% of the $^{90}Sr$ increment.

The discharge of $^{90}Sr$ from plant sources is, of course, independent of seasonal weather. The contribution of the sewage treatment plant to White Oak Creek is of primary importance during extended dry periods. The Operations Division has located an internal source of contamination, and has applied a corrective measure (L. Lasher, personal communication). The $^{90}Sr$ discharge from this plant source should thus be reduced significantly in 1979 and subsequent years. At that time, it may become necessary to investigate plant effluents above monitoring station 2, as the $^{90}Sr$ discharge at that point will probably assume much greater relative significance to the basin total.

The major conclusions from the study reported here are that SWDA 4 is the most important non-point source in the basin and is most significant in late winter and spring. Discharge from SWDA 5 into Melton Branch between its confluence with MBT and MS-4 (Fig. 2) probably is next most important and dominates during late summer low-flow conditions. Floodplain No. 1 was identified as next most important, followed by the sewage treatment plant, the Northwest Tributary, the process waste treatment plant and Waste Ponds 3539 and 3540.

The observations made during this rather brief study should be re-evaluated in terms of data collected over much longer periods of time. New permanent monitoring stations recently placed in operation will permit reliable determinations of the $^{90}Sr$ discharges from SWDAs 4 and 5 on a monthly basis. However, the contributions from floodplain No. 1 cannot be adequately assessed without routine monitoring data from the Northwest Tributary. Furthermore, evaluation of the importance of other known sources within the White Oak Creek basin below monitoring stations 3 and 4 has not yet been completed, although planning is underway.

The identification of some of the existing non-point sources in the White Oak Creek basin has provided the foundation for more detailed studies as part of the ongoing program to develop corrective measures. Current studies are directed toward accurately pinpointing the major discharge areas, providing reliable information on hydrology of contaminated areas, and establishing baseline data that can be used to evaluate the effectiveness of future corrective treatments.

It is also anticipated that these results will lead to improved future disposal practices through the identification of existing problems.

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# APPENDIX A

Strontium-90 activity, stream flow, and $^{90}Sr$ discharge at each location monitored during this investigation

Table A-1. September 1978 data

| Period: | 1-9 | 10-16 | 17-23 | 24-30 |
|---|---|---|---|---|
| | | $^{90}Sr$ (pCi/ml) | | |
| NWT | 0.03 | 0.08 | 0.06 | 0.06 |
| T-2A | 9.32 | 8.47 | 8.38 | 7.79 |
| MB | 0.03 | 0.03 | 0.02 | 0.02 |
| MBT | 0.45 | 0.38 | 0.63 | 0.41 |
| | | FLOW ($m^3$) | | |
| NWT | 17116 | 14110 | 13459 | 12561 |
| T-2A | 265.2 | 530.1 | 53.7 | 12.2 |
| MB | 9151.5 | 12088 | 6949.1 | 4844.7 |
| MBT | 3139.4 | 3807.4 | 2259.4 | 2095.9 |
| | | $^{90}Sr$ DISCHARGE (mCi) | | |
| NWT | 0.54 | 1.08 | 0.79 | 0.74 |
| T-2A | 2.47 | 4.49 | 0.45 | 0.10 |
| MB | 0.29 | 0.33 | 0.16 | 0.09 |
| MBT | 1.41 | 1.46 | 1.43 | 0.87 |

Table A-2. October 1978 data

| Period: | 1-7 | 8-14 | 15-21 | 22-28 | 29-31 |
|---|---|---|---|---|---|
| | | $^{90}Sr$ (pCi/ml) | | | |
| NWT | 0.06 | 0.02 | 0.04 | 0.02 | 0.03 |
| T-2A | 6.67 | 6.04 | 7.12 | 6.98 | 7.43 |
| | | FLOW ($m^3$) | | | |
| NWT | 13139 | 13824 | 15096 | 17004 | 6974 |
| T-2A | 100.7 | 0 | 0 | 6.7 | 4.2 |
| | | $^{90}Sr$ DISCHARGE (mCi) | | | |
| NWT | 0.77 | 0.25 | 0.54 | 0.31 | 0.19 |
| T-2A | 0.67 | 0 | 0 | 0.05 | 0.03 |

Table A-3. November 1978 data

| Period: | 1-6 | 7-14 | 15-19 | 20-21 | 22-30 |
|---|---|---|---|---|---|
| | | | $^{90}Sr$ (pCi/ml) | | |
| NWT | 0.03 | 0.04 | 0.05 | 0.04 | 0.08 |
| T-2A | 6.26 | 7.12 | 7.03 | 7.48 | 6.71 |
| WOC-11 | 0.03 | 0.03 | 0.02 | 0.05 | 0.04 |
| WOC-7 | 0.04 | 0.03 | 0.04 | 0.06 | 0.08 |
| WOC-5 | 0.03 | 0.05 | 0.08 | 0.06 | 0.06 |
| WOC-3 | 0.06 | 0.05 | 0.13 | 0.09 | 0.16 |
| | | | FLOW ($m^3$) | | |
| NWT | 14485 | 21728 | 12333 | 3818 | 23833 |
| T-2A | 6.61 | 17.74 | 497.45 | 56.03 | 1413.9 |
| WOC-11 | 76730 | 97550 | 95890 | 23430 | 205250 |
| WOC-7 | 103680 | 131810 | 140700 | 31680 | 301250 |
| WOC-5 | 103680 | 131810 | 154640 | 31680 | 331040 |
| WOC-3 | 103680 | 131810 | 154640 | 31680 | 331040 |
| | | | $^{90}Sr$ DISCHARGE (mCi) | | |
| NWT | 0.46 | 0.88 | 0.56 | 0.15 | 1.93 |
| T-2A | 0.04 | 0.13 | 3.50 | 0.42 | 9.49 |
| WOC-11 | 2.07 | 3.08 | 2.16 | 1.27 | 7.40 |
| WOC-7 | 3.74 | 4.16 | 5.07 | 1.86 | 24.43 |
| WOC-5 | 3.27 | 6.53 | 12.54 | 1.86 | 20.88 |
| WOC-3 | 6.54 | 7.12 | 20.90 | 2.85 | 53.68 |

Table A-4. December 1978 data

| Period: | 1-9 | 8-15 | 16-23 | 24-31 |
|---|---|---|---|---|
| | | $^{90}Sr$ (pCi/ml) | | |
| NWT | 0.11 | 0.04 | 0.05 | 0.07 |
| T-2A | 4.68 | 5.54 | 5.31 | 5.99 |
| WOC-7 | 0.10 | 0.07 | 0.07 | 0.05 |
| WOC-5 | 0.05 | 0.08 | 0.08 | 0.06 |
| WOC-3 | 0.22 | 0.14 | 0.14 | 0.15 |
| OWOC-2 | 0.81 | 1.13 | 1.13 | 1.49 |
| OWOC-1A | - | 3.24 | 3.51 | 3.65 |
| OWOC-14 | - | 0.03 | 0.01 | 0.01 |
| OWOC-T | - | 0.04 | 0.05 | 0.06 |
| | | FLOW ($m^3$) | | |
| NWT | 45856 | 37485 | 31633 | 33239 |
| T-2A | 9729.2 | 3235.5 | 4010.3 | 2492 |
| WOC-7 | 272331 | 287774 | 200567 | 164875 |
| WOC-5 | 299265 | 316235 | 220403 | 181181 |
| WOC-3 | 299265 | 315235 | 220403 | 181181 |
| OWOC-2 | 5197 | 1640 | 2066 | 1357 |
| OWOC-1A | 42.52 | 49.77 | 79.66 | 22.76 |
| OWOC-14 | 388.2 | 168.7 | 302.4 | 127.8 |
| OWOC-T | 1420 | 511.3 | 1081 | 448.3 |
| | | $^{90}Sr$ DISCHARGE (mCi) | | |
| NWT | 5.16 | 1.52 | 1.57 | 2.25 |
| T-2A | 45.58 | 17.93 | 21.32 | 14.93 |
| WOC-7 | 26.99 | 20.74 | 14.46 | 8.91 |
| WOC-5 | 14.83 | 24.22 | 16.88 | 11.43 |
| WOC-3 | 66.05 | 45.58 | 31.77 | 26.93 |
| OWOC-2 | 4.21 | 1.85 | 2.33 | 2.02 |
| OWOC-1A | 0.15 | 0.16 | 0.28 | 0.08 |
| OWOC-14 | 0.01 | 0.01 | 0.00 | 0.00 |
| OWOC-T | 0.07 | 0.03 | 0.05 | 0.03 |

Table A-5. January 1979 data

| Period: | 1-5 | 6-10 | 11-19 | 20-26 | 27-31 |
| --- | --- | --- | --- | --- | --- |
| | | | $^{90}Sr$ (pCi/ml) | | |
| NWT | 0.08 | 0.08 | 0.09 | 0.05 | 0.05 |
| | | | FLOW ($m^3$) | | |
| NWT | 37340 | 35432 | 27651 | 43871 | 18939 |
| | | | $^{90}Sr$ DISCHARGE (mCi) | | |
| NWT | 2.86 | 2.87 | 2.37 | 1.98 | 1.02 |

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